MODELLING AND PERFORMANCE EVALUATION OF FREE SPACE OPTICAL LINK FOR GROUND-TO-TRAIN COMMUNICATIONS

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A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy in Electrical Engineering

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DECEMBER 2019

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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“To Almighty Allah, who gave me strength and wisdom to complete this work, To my beloved family, my dear father and mother. To my brothers Dr. Wael, Dr. Mohammed Al-Wathiq and Dr. Waleed. To my sister Wafa and my brother's Wadah soul. For Their pure love, devotion, care and prays that helped me along the way. To My Supervisor for his patience and guidance, to my friends and colleagues, for their love, care, commitment and sincerity that motivated me to finish this valuable work”

ACKNOWLEDGEMENT

First and foremost, I thank Allah Almighty the greatest, the most merciful, the most compassionate, the knower of all, the first and the last. For endowing me with health, patience, and knowledge to complete this work.

I would like to express my unlimited gratitude and deepest appreciation for all my family members, with a special prayer to my beloved brother, Waddah may Allah rest his soul in heavens. And my close friends and all those who provided me the possibility to complete this research. A special gratitude I give to my research supervisor. Prof. Dr. Mohammad Faiz Liew Bin Abdullah whose contribution in stimulating suggestions and encouragement, helped me to coordinate my research especially in opening doors for rescue whenever I needed help.

Furthermore, I would like also to acknowledge with much appreciation the crucial role of staff of UTHM Office for Research, Innovation, Commercialization and Consultancy Management (ORICC) for their support under their Graduate Research Incentive Program GIPS with a Grant No. U.281. In addition to both the Faculty of Electrical and Electronic Engineering (FKEE) and Center of Graduate Studies(CGS), who gave access all required data and the necessary information to complete this research work.

I am also thankful to all my dearest friends for their moral support and motivation at every step along the way.

ABSTRACT

There is an increased demand for high-speed train (HSR) services. Consequently, onboard high-speed internet access needs increased as passengers travel to and from work. This sudden surge in demand introduced new challenges in delivering a seamless internet connection on-board fast-moving trains. Free Space Optical (FSO) Communications technology promises a bright future for various applications, due to its cost-effectiveness, ease of deployment, and huge unregulated bandwidth, which gives it an edge over contemporary technologies. However, there is a lack of significant research on FSO links for railway communications. In this thesis, straight, curved, and new double curved tracks mathematical models for FSO Ground-to-train (G2T-FSO) links have been proposed to overcome this issue and satisfy increased demand. G2T-FSO links feature base stations located beside the track to provide a LOS link for traveling trains. Moreover, FSO links comprise of intensity modulated transmitters with Direct detection receiver, that utilize RZ and NRZ OOK modulation formats at 2.5 Gbps. In addition, multiple transmitters concept has been implemented to enhance the link performance, in which single, dual, triple, and quad transmitters have been developed. Furthermore, geometrical parameters have been optimized to achieve optimal link performance. Measured meteorological data have been incorporated to simulate rain and fog weather attenuations. Performance evaluation has been conducted in terms of Received power, Q factor, SNR, BER, and Eye diagram patterns using MATLAB® and Optisystem®. Simulation results show significant effects of geometrical and atmospheric losses on single and dual transmitters link performances. However, Quad and triple transmitters have obtained a feasible error-free G2T-FSO link with BER of 10^{-9} for NRZ and RZ formats, significantly enhanced ranges of up to 680m for straight track and 618m for curved track under clear weather condition have been achieved. G2T-FSO links promise an unmatched performance over contemporary HSR communications technology.

ABSTRAK

Terdapat peningkatan permintaan untuk perkhidmatan kereta api berkelajuan tinggi. Oleh yang demikian, keperluan akses internet berkelajuan tinggi meningkat semasa pekerja pergi dan balik kerja. Pertambahan mendadak dalam keperluan ini telah menyebabkan cabaran baharu dalam memberikan hubungan internet selanjar bagi keretapi laju. Teknologi Komunikasi Optik *Free Space* (FSO) menjanjikan masa depan yang cerah bagi pelbagai aplikasi, disebabkan oleh kos-efektif, kemudahan mengatur kedudukan, dan jalur lebar yang besar serta tidak terkawal, yang membolehkannya keluar daripada teknologi yang kontemporari. Bagaimanapun, terdapat kurang kajian yang penting ke atas hubungan FSO untuk komunikasi kereta api. Dalam tesis ini, hubungan model matematik bagi track lurus, keluk, dan dua keluk baharu untuk Ground-to-train FSO (G2T-FSO) telah dicadangkan untuk menangani isu ini dan memenuhi peningkatan keperluan. Hubungan G2T-FSO menyediakan stesen penempatan yang terletak di sebelah trek untuk menyediakan hubungan LOS untuk kereta api yang bergerak. Tambahan pula, hubungan FSO merangkumi kekuatan pemancar modulasi dengan penerima pengesanan langsung, yang menggunakan format modulasi RZ dan NRZ OOK pada 2.5 Gbps. Tambahan lagi, konsep pemancar pelbagai telah dilaksanakan untuk menggalakkan prestasi hubungan, yang mana pemancar tunggal, ganda dua, ganda tiga dan ganda empat telah dibentuk. Lagi pula, parameter geometri telah dioptimumkan untuk mencapai prestasi hubungan optimum. Data meteorologikal yang diukur telah digabungkan untuk simulasi cuaca hujan dan kabut lemah. Penilaian prestasi telah dijalankan dalam hal Penerimaan kuasa, faktor Q, SNR, BER, dan corak rajah Mata menggunakan MATLAB® dan Optisystem®. Keputusan simulasi menunjukkan kesan penting pada kehilangan prestasi hubungan geometrikal dan atmosfera ke atas pemancar tunggal dan ganda dua. Bagaimanapun, pemancar ganda empat dan ganda tiga menerima hubungan bebas-kesalahan sesuai dengan BER bagi 10-9 untuk format NRZ dan RZ, pertingkatkan julat yang hetva

680 m untuk trek lurus dan 618 m untuk trek keluk di bawah keadaan cuaca cerah telah dicapai. Hubungan G2T-FSO menjanjikan prestasi tiada bandingan terhadap teknologi komunikasi kontemporari HSR

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LIST OF SYMBOLS

β_{FOV}	-	Field of View Angel
λ	-	Wavelength
f	-	Frequency
c	-	Speed of light (c=2.988x10^8 m/s),
$p(t)$	-	Normalized transmitted pulse shape
T_b	-	bit duration
t	-	Time
η	-	Quantum Efficiency
q	-	electron charge
$F(M)$	-	APD noise figure
I_M	-	average multiplied current
σ^2_{noise}	-	the variance of internal and external noises
$\sigma^2_{thermal}$	-	thermal noise variance
σ^2_{shot}	-	Shot noise variance
$\sigma^2_{Background}$	-	background illumination noise variance
$\langle i^2_{Thermal} \rangle$	-	thermal noise current
τ	-	Transmittance coefficient
γ_T	-	atmospheric attenuation coefficient
L	-	propagation length
γ_{abs}	-	absorption coefficient
α_{abs}	-	effective cross section of absorption particle

N_{abs}	-	concentration of absorption particle
γ_{Scat}	-	Scattering coefficient
N_{scat}	-	cross section of Scattering particle
α_{scat}	-	effective cross section of Scattering particle
$\gamma_{ScatTotal}$	-	Total Scattering coefficient
x_0	-	particle size
$\gamma_{Rayliegh}$	-	Rayleigh Scattering Coefficient
γ_{MIE}	-	Mie Scattering Coefficient
N_p	-	number of particle per unit volume
A_p	-	the cross section area of the particle
α_m	-	Mie scattering cross-section
N_a	-	density of aerosol molecule
$R_{mm/h}$	-	Rain precipitation rate
γ_{Rain}	-	rain attenuation
γ_{fog}	-	fog attenuation
q_{Kruse}	-	Kruse distribution size of particles
q_{KIM}	-	Kim distribution size of particles
$L_{Geometrical}$	-	Geometrical loss
$\delta_{Coverage}$	-	coverage angle at Point C
β	-	coverage angle at Point G
δ_{Cant}	-	cant (or superelevation) angle
ζ	-	residual lateral acceleration
$\zeta_{\max}$	-	Maximum residual lateral acceleration
γ_{Tilt}	-	Tilt angle
ϖ	-	angle between Tx_A and Rx_A
P_{Total}	-	Total power
$P_{Transmited(mW)}$	-	Total transmitted Power mW

N_{TX}	-	Number of Transmitters
LM	-	Link margin
$L_{Atmospheric}$	-	Total Atmospheric loss
L_{Tx}	-	Transmitter losses
L_{Rx}	-	Receiver losses
$N.B_{/10km}$	-	Number of Base Stations per 10km
$N.B_{/1km}$	-	Number of Base Stations per 1km
h	-	Planck's constant (6.63x10^{-34}Joules.Seconds).
α , k	-	rain attenuation coefficients
A_r	-	receiver aperture area
A_t	-	transmitter aperture area
B	-	Bandwidth
C	-	Arc length
d_H	-	Horizontal Distance parallel to rail track
d_V	-	Vertical distance parallel to rail track
E	-	Cant excesses
E1	-	Atom low Energy State
E2	-	Atom low Energy State
FFOV	-	Full field of view
G	-	Gain
g	-	acceleration of gravity
I	-	Cant deficiency
I_d	-	Dark current
I_{max}	-	Cant deficiency
I_P	-	received photocurrent
$L_{Coverage}$	-	Railway Track Coverage Length
L_p	-	transmission range
Lp	-	Pointing losses
M	-	APD multiplication factor
Nb	-	photons per bit (#Photon/bit)
Pin	-	received optical power

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